THE EFFECT OF VALVE OVERLAP ON DETONATION LIMITED ENGINE PERFORMANCE

by

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Submitted in Partial Fulfillment of

the Requirements for the Degree of

Master of Science

in

Aeronautical Engineering

from the

Massachusetts Institute of Technology

1947

Cambridge, Massachusetts,
June 1, 1947.

Professor Joseph S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

A thesis entitled "THE EFFECT OF VALVE OVERLAP ON DETONATION-LIMITED ENGINE PERFOMANCE" is herewith submitted in partial fulfillment of the requirements for the degree of Master of Science in Aeronautical Engineering.

Respectfully,

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the entire staff of Sloan Laboratories, M.I.T., for their aid in making this thesis possible, and in particular to Professor A. R. Rogowski, Professor W. D. Leary and Mr. J. C. Livengood for their indispensable suggestions and guidance.

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INTRODUCTION

The fact that detonation, or knocking, in an internal combustion engine is a function of many related and unrelated variables has caused considerable difficulty in the field of detonation research and engine design. To date, the practice has been to study the effect of these variables one at a time, endeavoring to hold all other variables constant. The purpose of this investigation is to hold all variables constant except the valve overlap and to thereby determine the detonation-limited characteristics of this variable alone.

Four different cam shafts, each with a different valve overlap, have been used in the investigation. The timing diagrams for these shafts are shown in Figure 1. In addition, the complete experiment has been conducted using two different types of fuel: (a) 80 octane automotive, and (b) di-iso-butylene.

SUMMARY

A series of tests have been conducted on a C.F.R. engine with camshafts whose valve overlap varied from 6° to 120°. In all cases the engine was operated at detonation limited inlet pressure. The tests were performed using two fuels: (a) 80-octane, and (b) di-iso-butylene.

The primary object of the tests was to determine the effect of varying valve overlaps on the detonation limited performance of the engine, and secondarily, to investigate the qualitative effect of residual gas on the fuel characteristics.

In the case of 80-octane, it was found that large overlaps permit the engine to develop greater power at high speed and that residual gas acts as an inhibitor.

In the case of di-iso-butylene, it was found that higher overlaps permit the development of higher power when running at low speeds and that overlap has relatively little effect on the power output at high speed. At the higher speeds the engine detonated at lower critical pressure, as previously discovered by other investigators, but no conclusion can be drawn as to the effect of residual gas on this reversal since, in these tests, this variable could not be isolated.

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In no case were idling difficulties encountered. However, at least one previous investigator* has found evidence that although a single cylinder engine will idle with high overlap timing, a multi-cylinder engine with similar timing will not. Although this phenomenon was not investigated in this experiment, it is believed to be due to intake and exhaust system dynamic effects.

* Young, A. W., N.A.C.A., A.P.R. (Nov. 1941).

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* Young, A. W., M.S.C.E., [illegible]

DESCRIPTION OF APPARATUS

ENGINE

A single cylinder, C.F.R., high speed, water-cooled engine having a 3.25-inch bore and a 4.50-inch stroke, was used at a compression ratio of 7 to 1. The engine was directly connected to an electric dynamometer which was employed both as a starter and power absorber for the engine, as well as a motor to turn the engine over while measuring friction torque. A shrouded intake valve was used to enhance distribution and mixing of the fresh charge in the cylinder and an Auto Lite B-5 spark plug was used to mitigate any tendencies toward pre-ignition.

FUEL SYSTEM

The fuel system is shown schematically in Figure 2. The fuel was taken from the fuel tank through a small electrically driven pump to a bubble separator and surge tank. Compressed air was pumped into the bubble separator and the pressure was held constant at 30 psi. This air acted as a "cushion" for the system. From the bubble separator the fuel was passed through one of two Fisher and Porter rotometers which had been calibrated by the authors prior to the experiment, as shown by Figure 3. From the rotometers the fuel flowed directly into the vaporizing tank.

AIR SYSTEM

The air system is shown schematically in Figure 2.

[illegible]

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FUEL SYSTEM

The fuel system is shown schematically in Figure 2. The fuel was taken from the fuel tank through a small electrically driven pump to a bubble separator and surge tank. Compressed air was pumped into the bubble separator and the pressure was held constant at 10 psi. This air acted as a "cushion" for the system. From the bubble separator the fuel was passed through one of two Fischer and Porter rotometers which had been calibrated by the manufacturer prior to the experiment, as shown by Figure 3. From the rotometers the fuel flowed directly into the vaporizing tank.

AIR SYSTEM

The air system is shown schematically in Figure 2.

Supercharged air was tapped directly from the laboratory main. It was then taken through two pressure regulators and metered through one of two flat plate orifices with flange taps. The smaller of the two orifices was .515 inches in diameter and the larger was .725 inches in diameter. Both orifices were constructed according to ASME specifications and inserted in 2-inch pipes. After being metered, the air passed through double surge tanks into the vaporizing tank.

VAPORIZING TANK

Air and liquid fuel were introduced into the vaporizing tank separately. The fuel was here vaporized and mixed with the air. The mixture was held at a constant temperature of 140°F. This temperature was controlled by the circulation of steam through heating coils within the tank. From the tank the fresh mixture passed through the throttle valve and into the engine.

OIL SYSTEM AND WATER JACKET SYSTEM

The jacket water temperature was held constant at 212°F. and was controlled by circulating water through a cooler between the condenser and the jacket. The oil temperature was held constant at 140°F. by means of circulating steam or cooling water through the two heat exchangers.

MEASURING INSTRUMENTS

The engine power output was absorbed by a Star electric dynamometer and the brake torque was balanced by a hydraulic

Supercharged air was tapped directly from the laboratory main. It was then taken through two pressure regulators and metered through one of two flat plate orifices with flange taps. The smaller of the two orifices was [illegible] inches in diameter and the larger was .755 inches in diameter. Both orifices were constructed according to A.S.M.E. specifications and inserted in 2-inch pipes. After being metered, the air passed through double surge tanks into the vaporizing tank.

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MEASURING INSTRUMENTS

The engine power output was absorbed by a [illegible] electric dynamometer and the brake torque was balanced by a hydraulic piston attached through a lever arm to the dynamometer casing. The oil pressure on the hydraulic system was measured in inches of mercury in an open end manometer. The hydraulic system was designed so that one inch of mercury was the equivalent of a one-pound force acting on the hydraulic piston. The reading of the dynamometer scale in inches of mercury was converted to pounds per square inch, brake mean effective pressure. The electric power output from the dynamometer was dissipated through a grid at low outputs and at higher outputs the power was pumped into 110-volt or 220-volt mains, depending upon the magnitude of the power generated.

Detonation was measured qualitatively by employing a detonation pickup in conjunction with a cathode ray oscilloscope. The pickup, a Draper flat diaphragm type with a natural frequency of about 95,000 cycles, was inserted in the cylinder head. The output from this pickup was analyzed and projected on the screen of the oscilloscope as a curve of relative rate of change of cylinder pressure vs time. When conditions of insipient detonation were reached, the curve displayed a definite break or "pip". The operator observing the "pip" also controlled the throttle.

Engine speed was roughly measured by using a tachometer, and for finer speed adjustment a strobotac was employed. Speed was controlled by a drop wire resistance in the shunt field of the dynamometer.

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Detonation was measured qualitatively by employing a detonation pickup in conjunction with a cathode ray oscilloscope. The pickup, a Trapet flat diaphragm type with a natural frequency of about 95,000 cycles, was inserted in the cylinder head. The output from this pickup was amplified and projected on the screen of the oscilloscope as a curve of relative rate of change of cylinder pressure vs time. When conditions of incipient detonation were reached, the curve displayed a definite break or "pip". The operator observing the "pip" also controlled the throttle.

Engine speed was roughly measured by using a tachometer, and for finer speed adjustment a stroboscope was employed. Speed was controlled by a drop wire resistance in the shunt field of the dynamometer.

PROCEDURE

The following table indicates the operating conditions which were held constant throughout the entire experiment:

Compression ratio	7.0
Fuel-Air ratio	0.08
Spark advance	18° B.T.C.
Oil temperature	140° F.
Water jacket temperature	212° F.
Inlet mixture temperature	140° F.

The following quantities were varied:

Valve overlap	6° - 120°
Manifold pressure	20 - 80 " Hg
RPM	1000 - 3000
Exhaust pressure	30 - 6 " Hg

Each camshaft (with valve timings as per Figure 1) was in turn installed in the engine and two tests were performed. Test no. 1 consisted of varying the R.P.M. and running up the manifold pressure until insipient detonation was reached. Test no. 2 consisted of operating the engine at constant R.P.M. (2000), steadily reducing the exhaust back pressure, and then running up the manifold pressure until insipient detonation was reached. Both of these tests were performed using two fuels (80-octane and di-iso-butylene).

As the insipient detonation points were approached, adjustment of the fuel-air ratio was obtained by computing

PROCEDURE

The following table indicates the operating conditions which were held constant throughout the entire experiment:

Compression ratio	7.0
Fuel-Air ratio	0.08
Spark advance	15° B.T.C.
Oil temperature	140° F.
Water jacket temperature	212° F.
Inlet mixture temperature	140° F.

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Manifold pressure	20 - 80 " Hg
RPM	1000 - 2000
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As the incipient detonation points were approached, adjustment of the fuel-air ratio was obtained by computing the mass of air flow by the orifice equation, entering the rotometer calibration chart with the mass of fuel flow desired to give a fuel-air ratio of .08, and adjusting the fuel flow until the rotometer showed the proper scale reading. The manifold pressure was then varied until insipient detonation occurred. The above procedure was repeated until a "no change" condition was reached.

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DISCUSSION (80 OCTANE)

From Fig. 6 it is noted that as the residual gas is "sucked" out of the cylinder due to decreasing the back pressure, the allowable Pi is progressively lowered in the case of the 6° overlap cam, and it is therefore apparent that residual gas has an inhibiting effect on detonation.

Still referring to Fig. 6, it might reasonably follow that if this is true, the higher overlaps should give even less detonation limited Pi. However, in the case of the higher overlaps, more fresh mixture is consumed per cycle, tending to cool the engine parts. This increased cooling may overshadow the effect of reduced residual gas and thereby permit higher allowable Pi's.

Referring to Fig. 4, it is noted that at low speed (1000 RPM), higher overlaps permit higher allowable Pi's. At this speed the inlet pressure is always less than the exhaust pressure. Since the mixture consumption per cycle is approximately constant (at 1000 RPM), as seen by Fig. 9, differences in engine parts temperature due to this effect are negligible. However, two other effects influence the amount of residual back flow, (a) the pressure gradient between Pe and Pi, and (b) the overlap which changes the time available for the back flow to take place. If it is assumed that residual gas acts as an inhibitor, it follows that at 1000 RPM the residual gas content is progressively higher with greater overlaps. As the engine speed is in-

From Fig. 8 it is noted that as the residual gas is "pushed" out of the cylinder due to increasing the inlet [illegible] pressure, the calculated η is progressively lower in the case of the 8° overlap cam, and it is therefore [illegible] that residual gas has an important effect on detonation.

Still referring to Fig. 8, the increasing [illegible] that if this is true, the larger overlaps should have much less detonation limited [illegible] of the higher overlaps, more fresh [illegible] tending to cool the engine parts. This increased cooling may overshadow the effect of reduced residual gas [illegible] permit higher allowable [illegible].

Referring to Fig. 9, it is seen that at the high speed (1000 RPM), higher overlaps result in [illegible] lowering [illegible]. At this speed the inlet pressure is always less than the exhaust pressure. Since the mixture consumption per cycle is approximately constant (at 1000 RPM) as seen in Fig. 9, differences in engine parts temperature due to this effect are negligible. However, two other effects influence the amount of residual back flow, (a) the pressure gradient between Pe and Pi, and (b) the overlap which changes the time available for the back flow to take place. If it is assumed that residual gas acts as an inhibitor, it follows that at 1000 RPM the residual gas content is progressively higher with greater overlaps. As the engine speed is increased, both the pressure gradient and the time available for scavenging are reduced, and at 3000 RPM all overlaps show approximately the same detonation limited Pi's.

Fig. 6 indicates that overlap has little effect on detonation limited IHP at low speed, but that overlap increases the IHP appreciably at 3000 RPM. It is to be noted that at this speed the highest overlap gives the maximum power, but that a reduction in overlap of 50% reduces the power by only 7%.

At 2000 RPM, Fig. 7 indicates that for all overlaps greater than 60^{o}, the variation of IHP with altitude is negligible. If these runs had been conducted at a lower speed, the overlap effect might have become more pronounced due to greater time available for purging, or back flow, as the case might be.

Fig. 8 indicates that low overlaps have the better volumetric efficiencies at low speed, but that a reversal takes place such that the high overlaps give the better volumetric efficiencies at high speed. This reversal is due to the fact that at low speed Pi is less than Pe, while at high speed Pi is greater than Pe (Fig. 4).

DISCUSSION (DI-ISO-BUTYLENE)

In the case of di-iso-butylene, the determination of insipient detonation was exceedingly more difficult than in the case of 80-octane. During the early stages of operation, the authors were somewhat deceived by what was observed on the oscilloscope. When the inlet pressure was increased to the point where a distinct "pip" was observed on the scope, it was assumed that insipient detonation was reached in that the pip resembled that obtained when insipient detonation occurred with 80-octane. However, it was later discovered that after the initial "pip" appeared, its intensity was unaltered by either radical changes in spark timing or large increases of manifold pressure (in the order of magnitude of 12 to 18 inches of Hg). After this discovery, the initial "pip" was disregarded and insipient detonation was only assumed to be present when an increase in manifold pressure noticeably increased the "pip's" magnitude. This fact necessitated a re-run of the 6° overlap shaft on di-iso-butylene for varying RPM's and the re-run was performed at the conclusion of the other runs. However, the new data was erringly placed in table I and also appears in figure 13 for the low overlap. These four points should be raised by about 15" Hg.

The running of di-iso-butylene in addition to 80-octane was undertaken to determine if the commonly observed reversal of critical pressure-speed relations, as compared with 80-octane, would persist in the case of large variations in

In the case of di-iso-butylene, the correlation of incipient detonation was exceeding [illegible] than in the case of 80-octane. During the early [illegible] ation, the uniform [illegible] served on the oscilloscope. [illegible] increased to the point where [illegible] constantly on the scope, it was assumed that incipient detonation was reached in that the pip present [illegible] in- cipient detonation occurred with [illegible]. However, it was later discovered that after the initial "pip" appeared, its intensity was unaltered by either advanced changes in spark timing or large increases in manifold pressure (in the order of magnitude of 12 to 15 inches Hg). After this discovery, the initial "pip" was disregarded and in- cipient detonation was only assumed to be present when an increase in manifold pressure noticeably increased the "pip's" magnitude. This fact necessitated a re-run of the 6° overlap chart on di-iso-butylene for varying rpm's and the re-run was performed at the conclusion of the other runs. However, the new data was wrongly placed in table 1 and also appears in figure 13 for the low overlap. These four points should be raised by about 15" Hg.

The running of di-iso-butylene in addition to 80-octane was undertaken to determine if the contrary observed reversal of critical pressure-speed relations, as occurred with 80- octane, would persist in the case of large variations in residual gas concentration. It was suspected that residual gases might exert either a catalytic or an inhibiting effect on the auto ignition of the last part of the charge to burn. At the time of this investigation, the effect of residual content on time reversal was being concurrently studied by Lieutenant Commander J. M. Richards, et al, under carefully controlled experimental conditions and it was anticipated that the two investigations would perhaps substantiate each other through the viewpoint of different experimental parameters. The work of Richards, et al, showed conclusively that residual gas has no appreciable effect either as a catalyst or as an inhibitor on the observed reversal. Although the investigation presented herein also shows the reversal (Fig. 10), no theory can be propounded by this experiment in view of the fact that residual gas effects are negligible. Sloan Laboratories, M.I.T., have shown the reversal to be due to a time effect (rapidity of compression).

It is believed by the authors that for similar investigations in the future, better results might be obtained by increasing the inlet temperature of the fresh mixture above 140°F since this fuel is relatively insensitive to pressure.

As observed from Figs. 11 and 12, the effect of overlap on detonation limited Pi is negligible with a slight tendency toward higher Pi's for higher overlap in the case of 80-octane and lower Pi's for the high overlaps with di-iso-butylene.

The IHP is progressively greater for higher overlaps at 1000-1100 RPM, and at increasing speeds the effect of overlap

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studied by Lichtenstein [illegible]
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It is believed by the authors that for similar investi-
gations in the future, better results might be obtained by
increasing the inlet temperature of the fuel [illegible] above
110°F since this fuel is relatively insensitive to pressure.

As observed from Figs. 11 and 12, the effect of overlap
on detonation limited PI is negligible with a slight tendency
toward higher PI's for higher overlap in the case of 70-octane
and lower PI's for the high overlaps with di-iso-butylene.

The IMP is progressively greater for higher overlaps at
1000-1100 RPM, and at increasing speeds the effect of overlap

becomes less important since the IMEP is substantially constant (Fig. 8). It is believed certain that the 120° overlap point at 2100 RPM (Fig. 8) is considerably in error and that the IMEP for this point should be about 185, as shown by Fig. 7 at Pe = 30 and RPM = 2000. The error is unquestionably due to a personnel oversight. Time permitting, this shaft would be inserted in the engine and the point recomputed.

Fig. 15 indicates extensive blow through for the high overlap cam at 1100 RPM.

CONCLUSIONS (80-OCTANE)

For maximum detonation limited IHP optimum valve overlap depends upon engine speed.

Overlap has little effect on detonation limited IHP at low speed.

Higher overlaps give higher allowable IHP's at high speed.

No appreciable gain is obtained in the indicated output for overlaps greater than 60°.

At a speed of 2000 RPM the indicated output changes negligibly with decreases in back pressure for all overlaps of 60° or greater.

Residual gas has an inhibiting effect on the detonation tendencies of this fuel.

It has previously been established that residual gas acts as an inhibitor in the case of iso-octane fuel.*

* N.A.C.A., T.R. #699 (1940).

CONCLUSIONS (DI-ISO-BUTYLENE)

This fuel, as compared with 80-octane, permits higher detonation limited inlet pressure and higher engine output under all conditions investigated.

This fuel is relatively insensitive to pressure.

As the speed is increased, the allowable fresh mixture consumption per cycle is reduced, resulting in the peak pressure reversal observed by previous investigators.

No conclusion is drawn as to the effect of residual gas on the detonation characteristics of this fuel.

The high allowable Pi at low speeds causes excessive "blow through" when using the 120° overlap cam.

Valve overlap has relatively little effect on detonation limited inlet pressure.

Greater overlaps permit the development of higher IHP's at low speed, but as the speed is increased, the IHP is substantially constant for all overlaps.

SYMBOLS

B.L.	Brake loading	"Hg.
e	Volumetric efficiency	-
FL	Friction loading	"Hg.
F/A	Fuel air ratio	-
Fuel Cons.	Fuel consumption	#/sec.
Imep	Indicated mean effective pressure	Psia.
IHP	Indicated horse power	H.P.
Isfc	Indicated specific fuel consumption	$\frac{\text{\# fuel}}{\text{IHP-hr.}}$
Ma	Air consumption	#/sec.
O	Orifice in use	-
ΔP	Pressure across air orifice	"H_2O
Pb	Pressure before air orifice (abs.)	"Hg.
Pe	Exhaust manifold pressure (abs.)	"Hg.
Pi	Inlet manifold pressure (abs.)	"Hg.
R	Rotometer in use	-
Roto	Rotometer reading	-
Tb	Temp. before air orifice	^{o}F
Vd	Engine displacement volume (37.33 cu.in.)	-
ρi	Inlet mixture density	$\frac{lb}{ft^3}$

EQUATIONS

For .515" orifice:

$$\text{Air consumption} = .01825 \left(\frac{P_b \times \Delta P}{T_b + 460}\right)^{\frac{1}{2}}$$

For .725" orifice:

$$\text{Air consumption} = .0365 \left(\frac{P_b \times \Delta P}{T_b + 460}\right)^{\frac{1}{2}}$$

$$\text{Fuel consumption} = (0.08) \times \text{Air consumption}$$

$$\text{Imep} = (BL + FL)(4.245)$$

$$\text{IHP} = \frac{(BL + FL)(RPM)}{5000}$$

$$\text{Isfc} = \frac{\#\ \text{fuel/hr}}{\text{IHP}}$$

$$e = \frac{(\text{Const.})M_a}{\rho_i \times V_d \times RPM}$$

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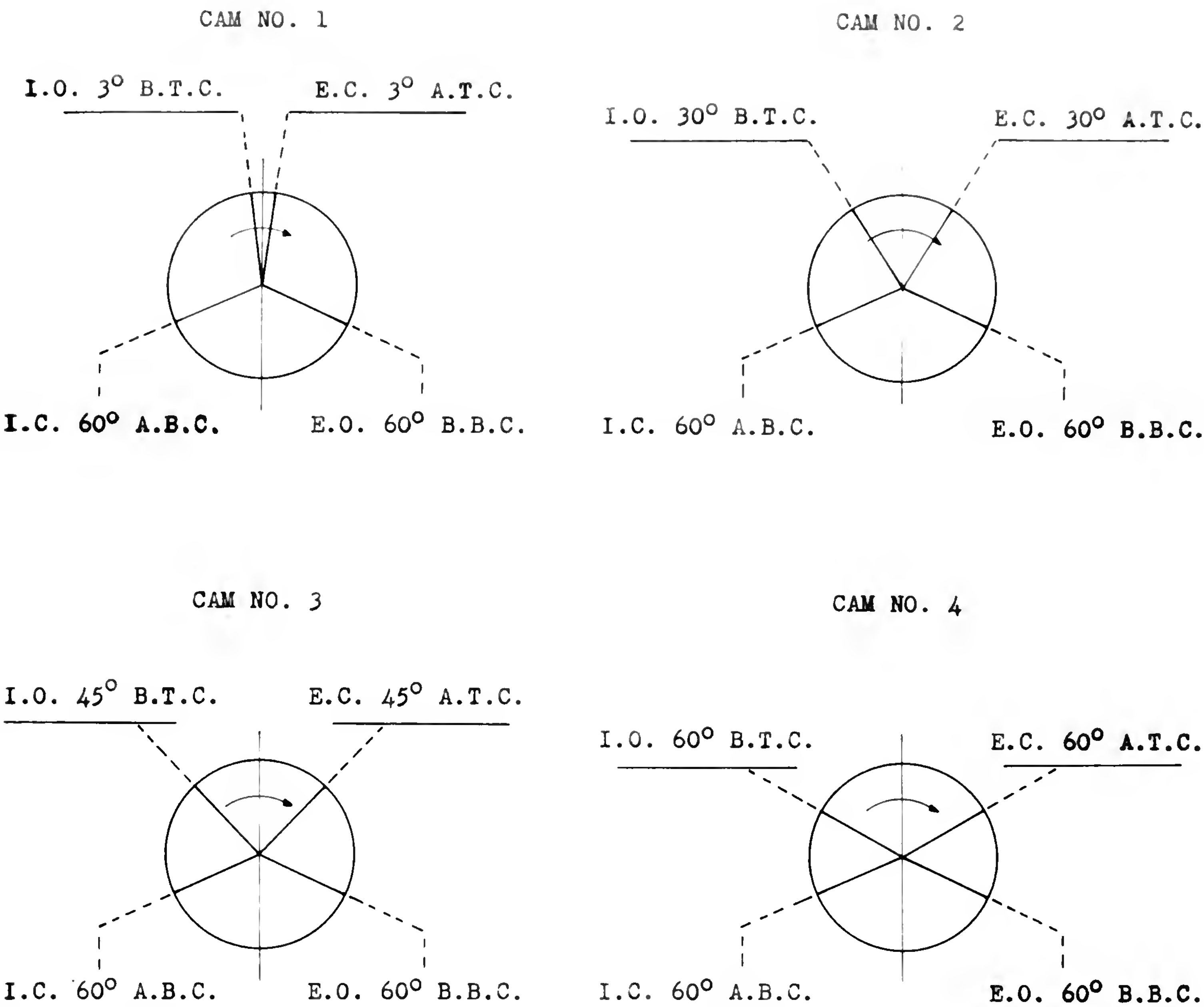
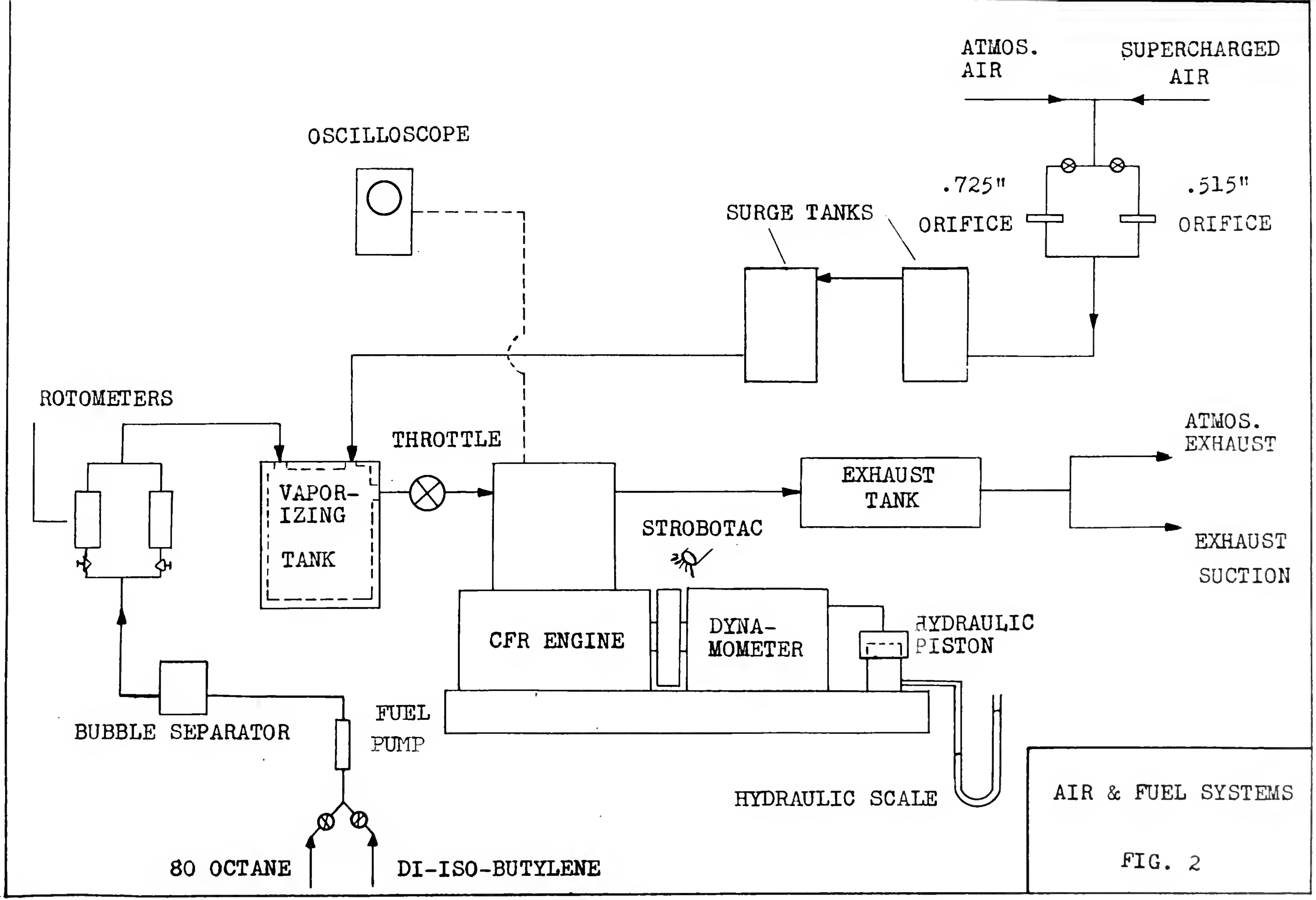


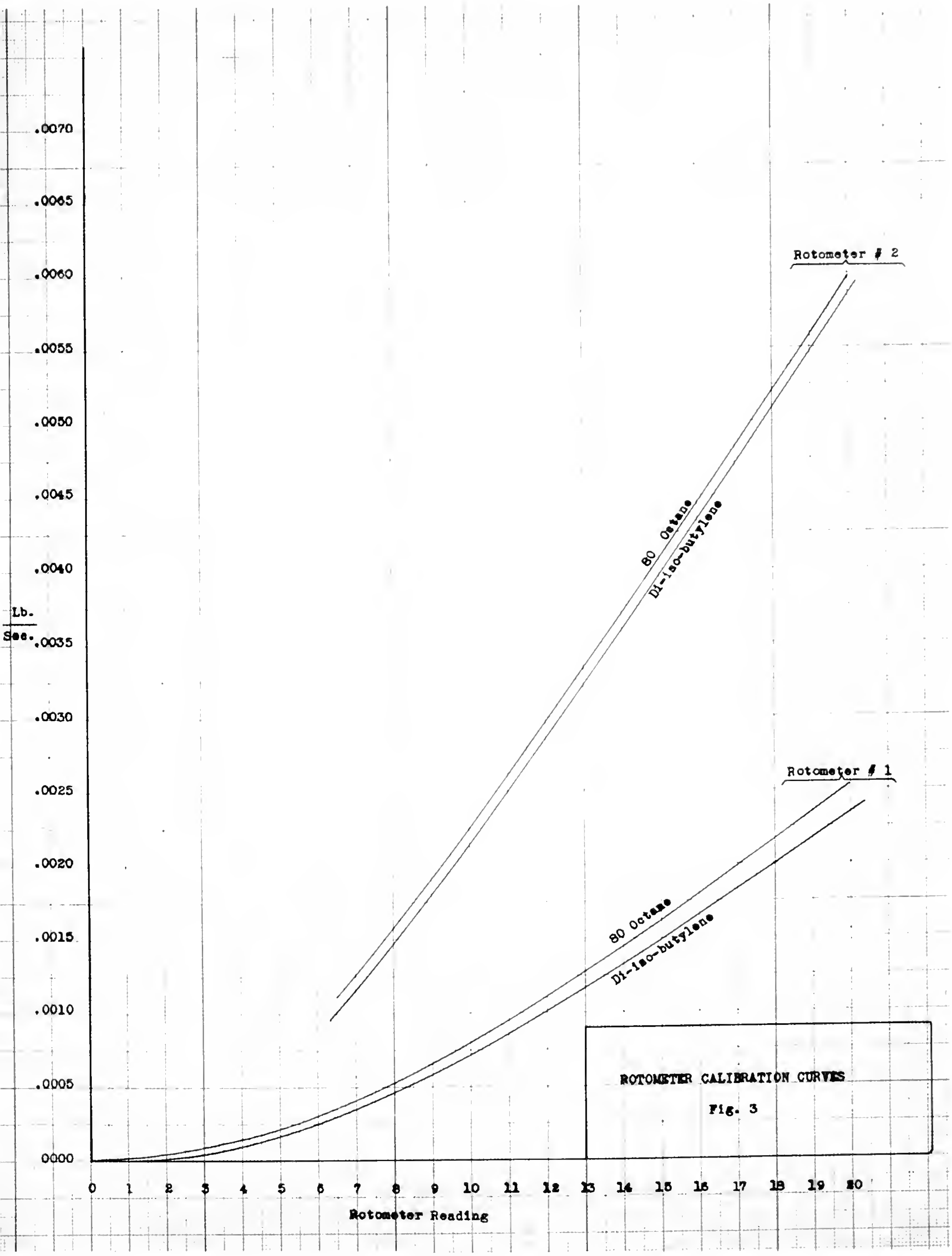
CAMSHAFT TIMING DIAGRAMS

FIG. 1



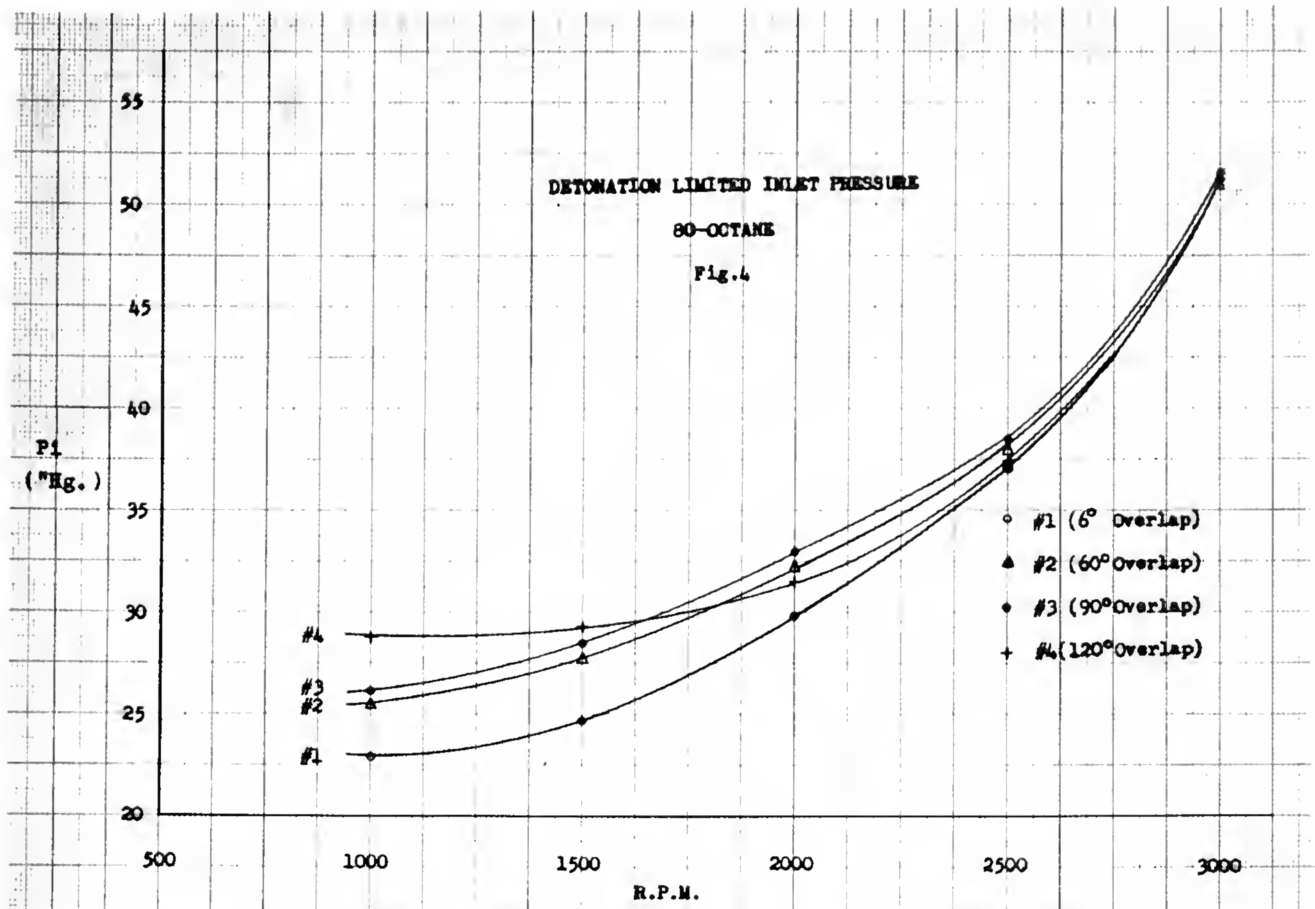
AIR & FUEL SYSTEMS

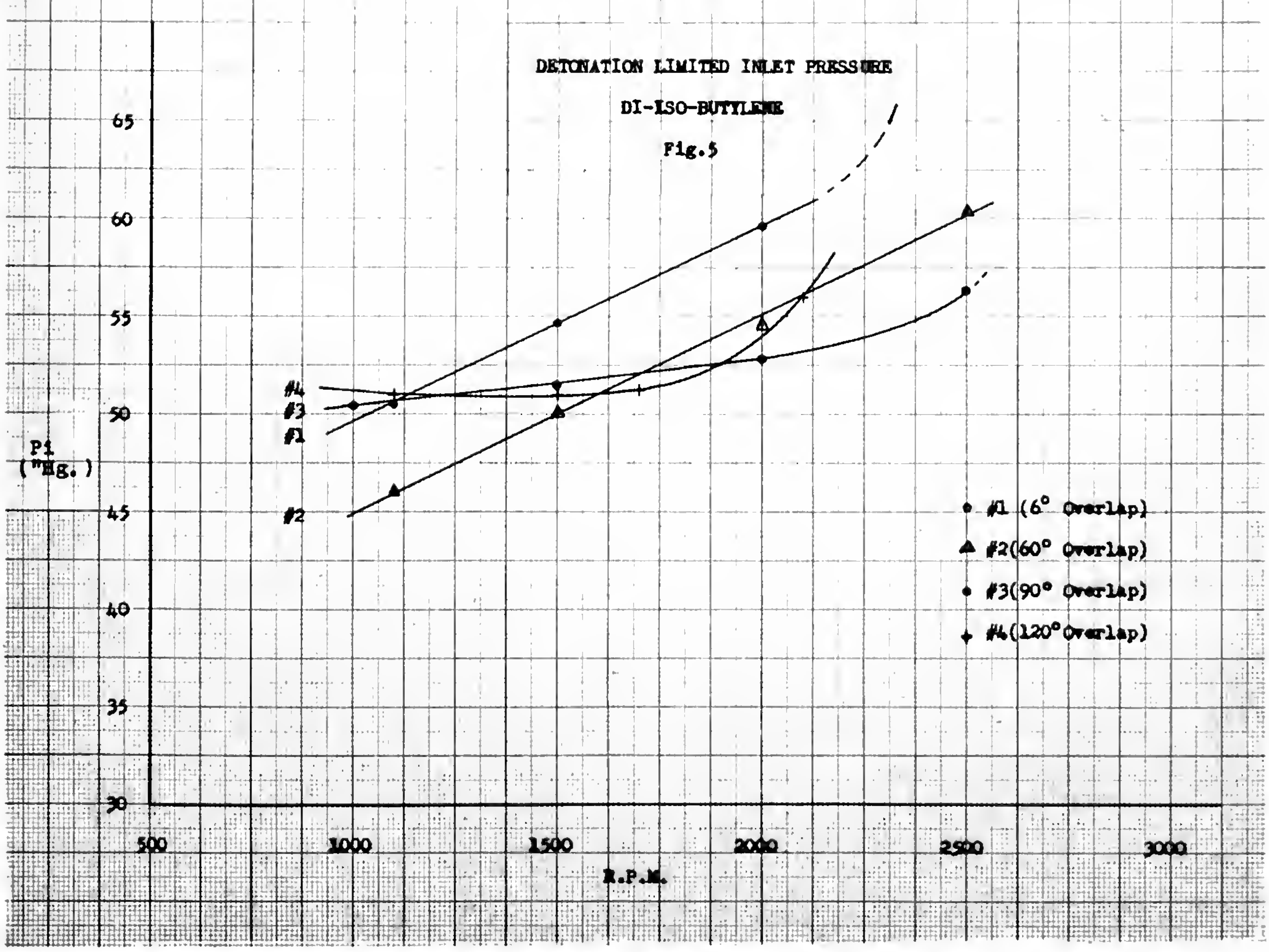
FIG. 2



ROTOMETER CALIBRATION CURVES

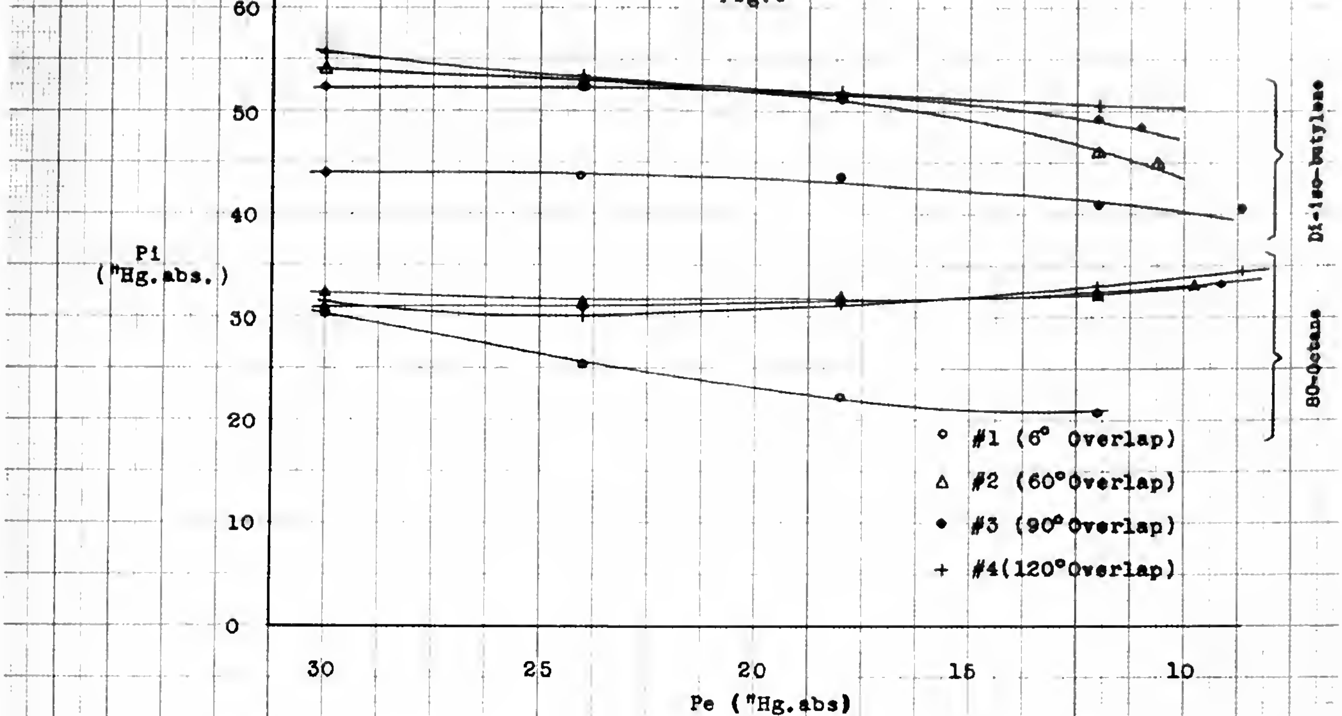
Fig. 3


DETONATION LIMITED INLET PRESSURE
80-OCTANE
Fig.4
Pi ("Hg.)
R.P.M.
#1 (6° Overlap)
#2 (60° Overlap)
#3 (90° Overlap)
#4 (120° Overlap)
#1
#2
#3
#4
20
25
30
35
40
45
50
55
500
1000
1500
2000
2500
3000


DETONATION LIMITED INLET PRESSURE
DI-ISO-BUTYLENE
Fig.5
Pi ("Hg.)
R.P.M.
#1 (6° Overlap)
#2 (60° Overlap)
#3 (90° Overlap)
#4 (120° Overlap)
#1
#2
#3
#4
30
35
40
45
50
55
60
65
500
1000
1500
2000
2500
3000

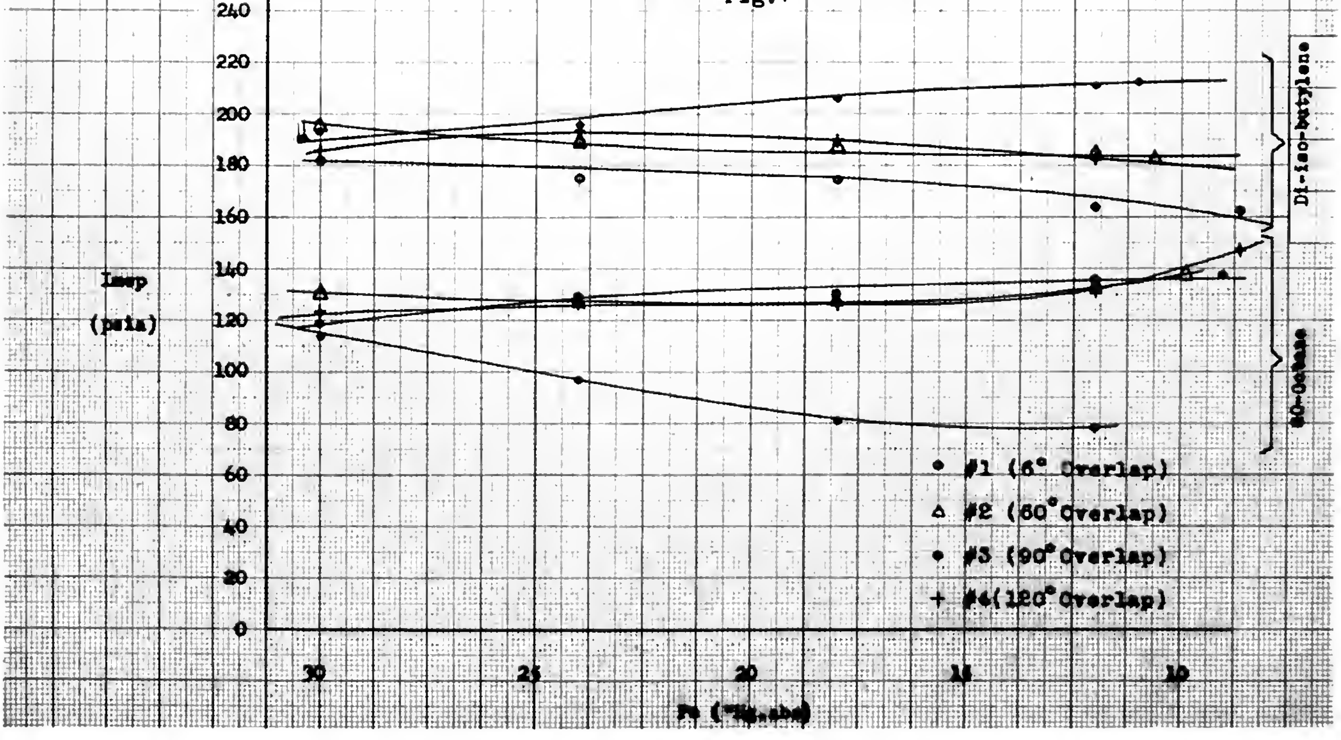
DETONATION LIMITED INLET PRESSURE

Fig.6



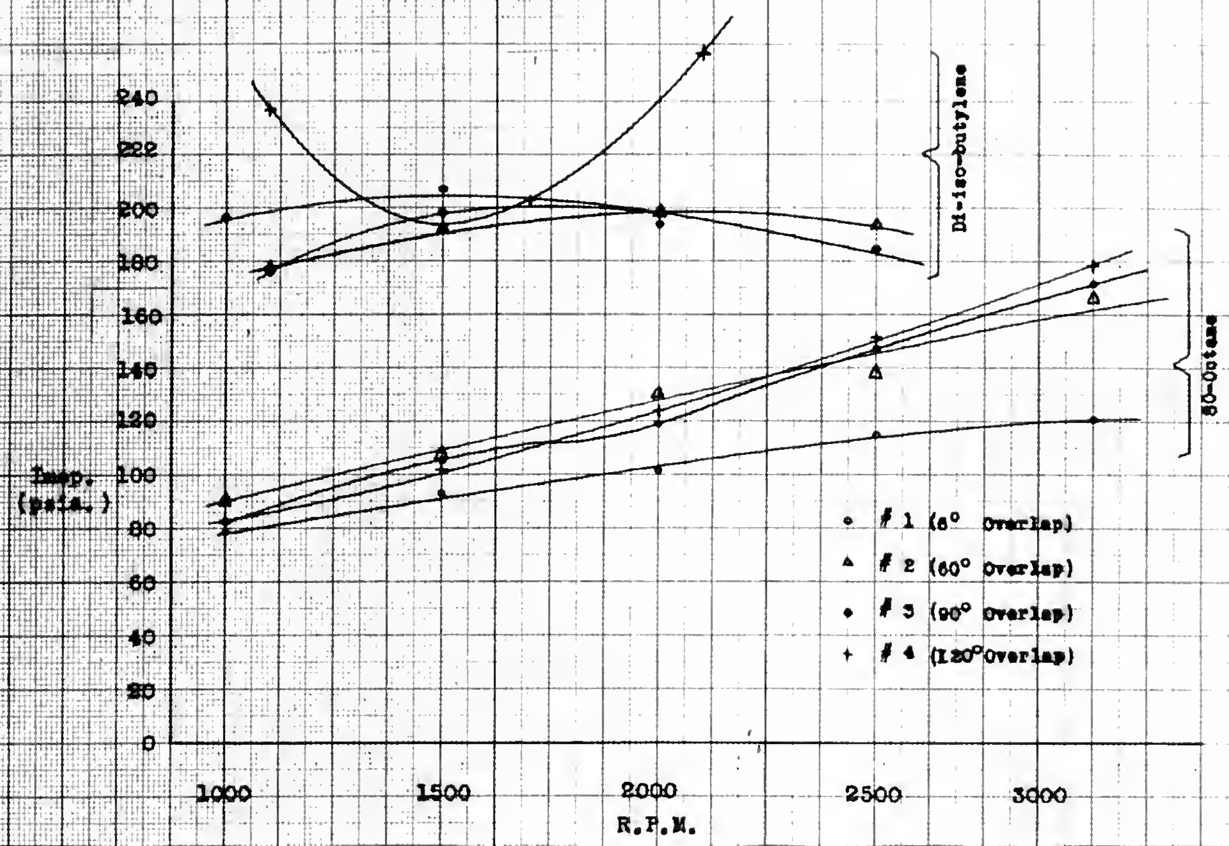
DETONATION LIMITED Imep

Fig.7



DETONATION LIMITED Imep.

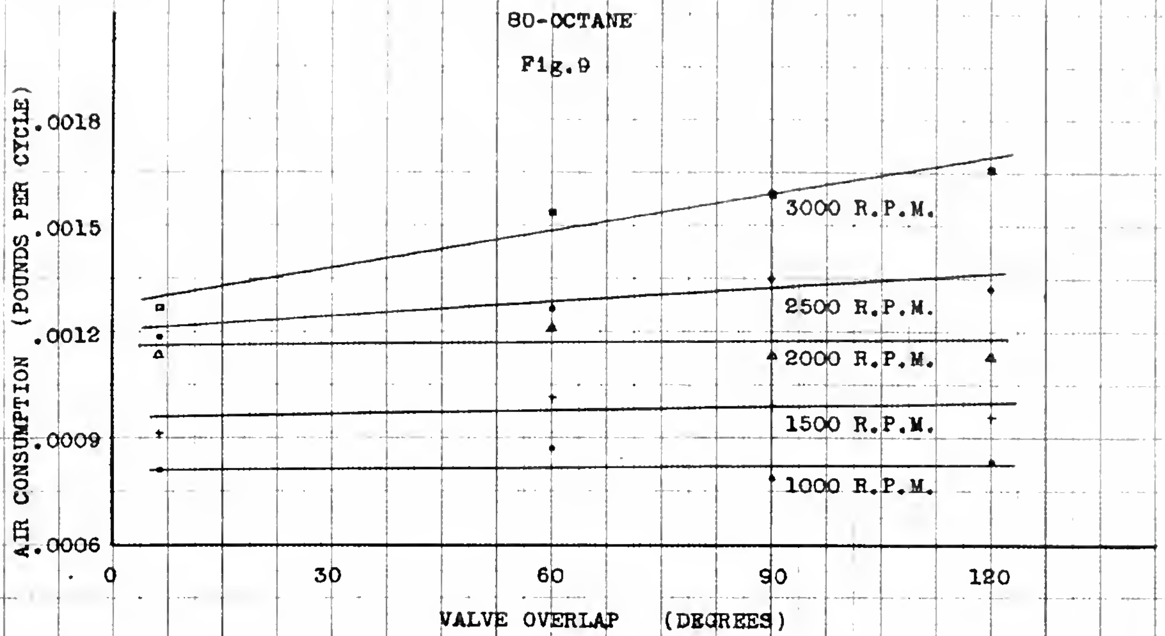
Fig. 8



AIR CONSUMPTION PER CYCLE

80-OCTANE

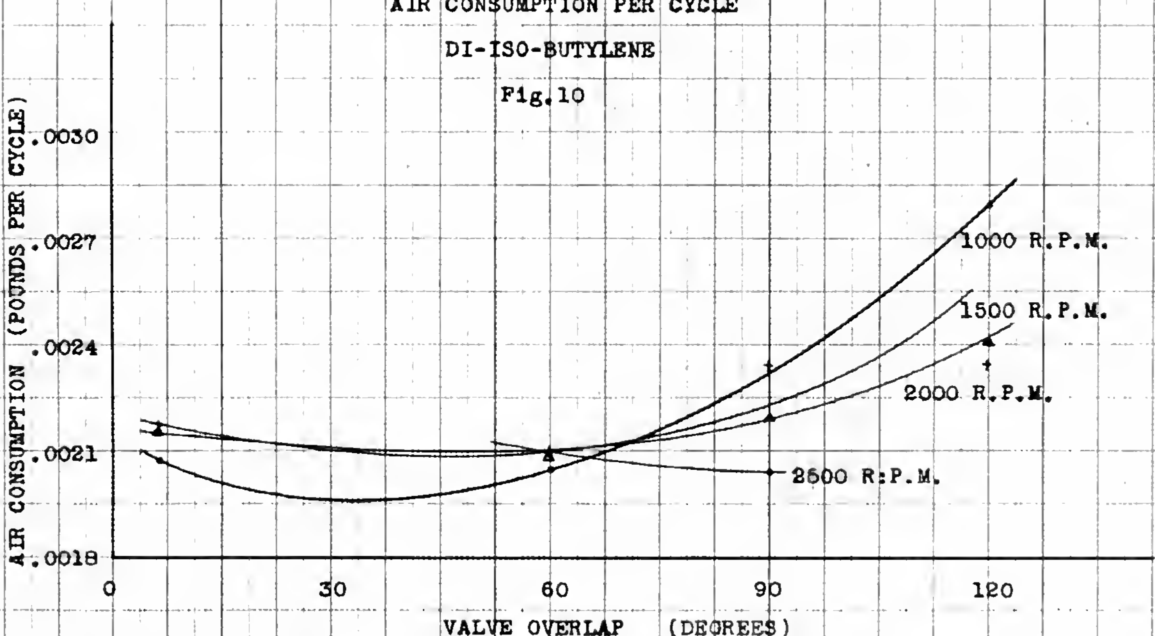
Fig.9

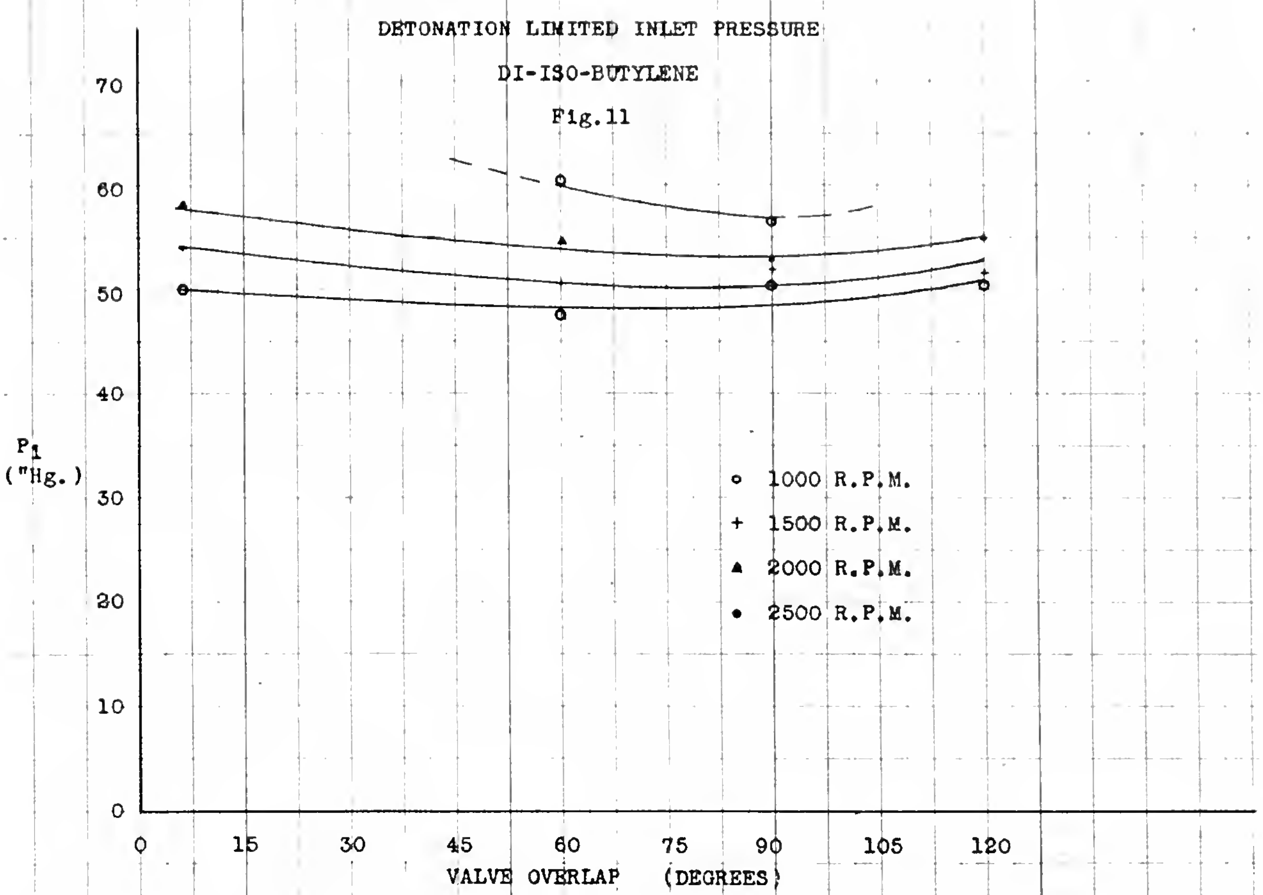


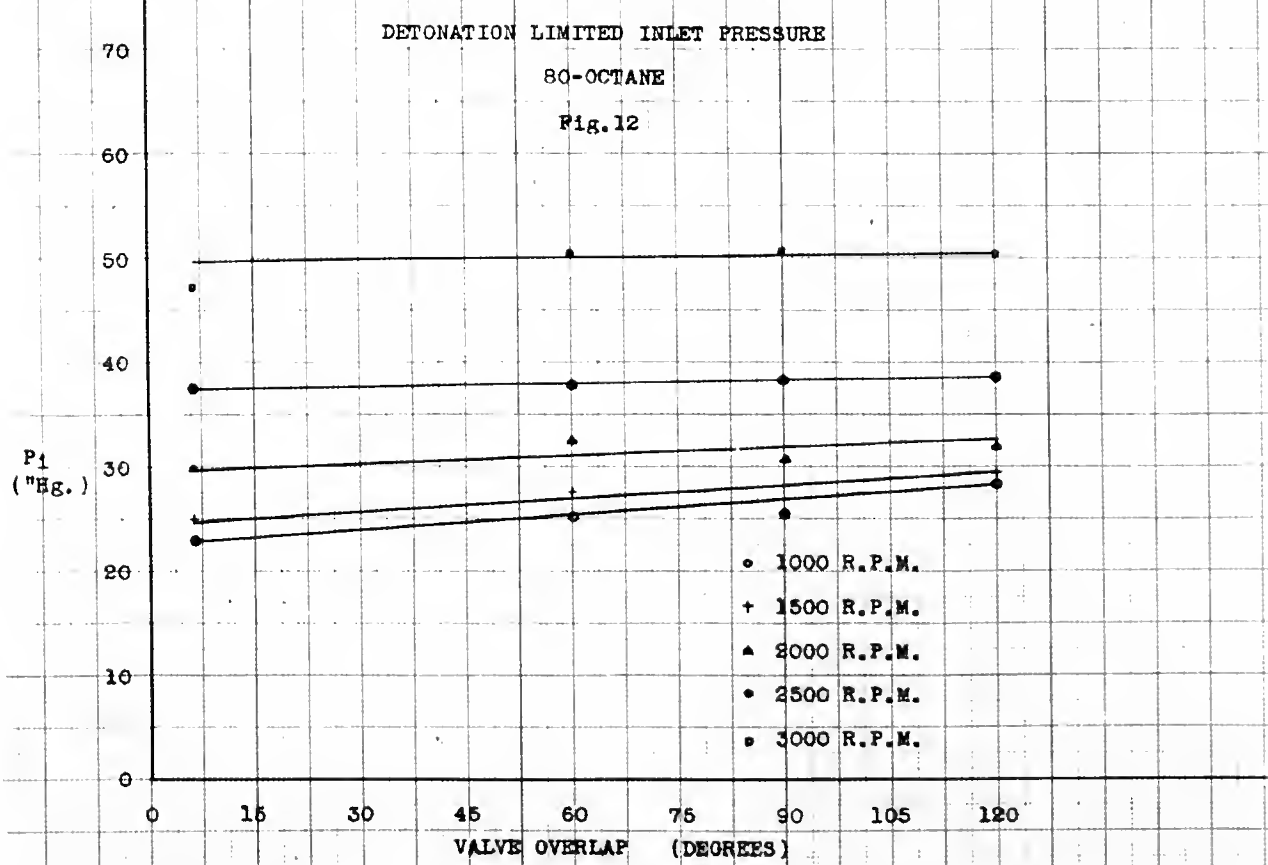
AIR CONSUMPTION PER CYCLE

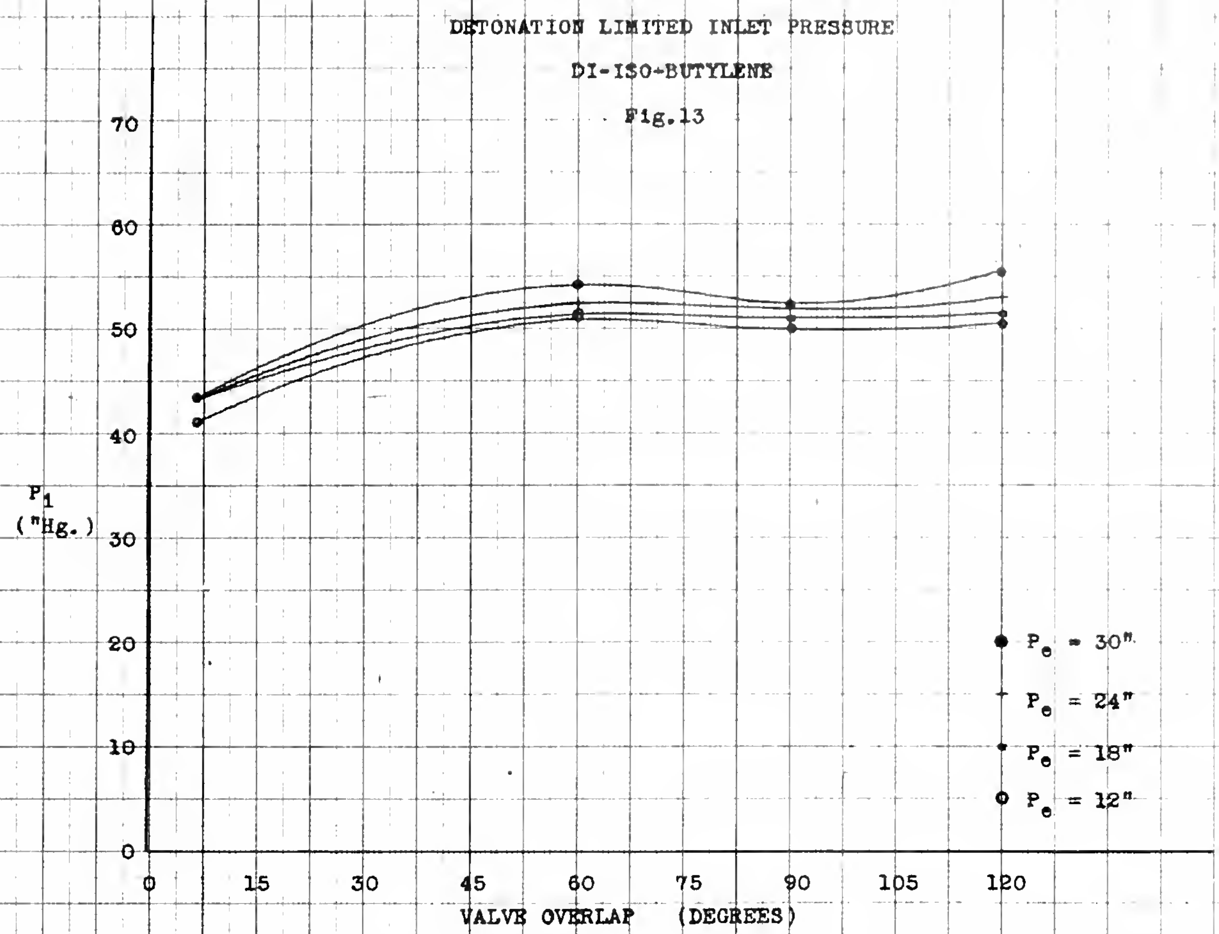
DI-ISO-BUTYLENE

Fig.10

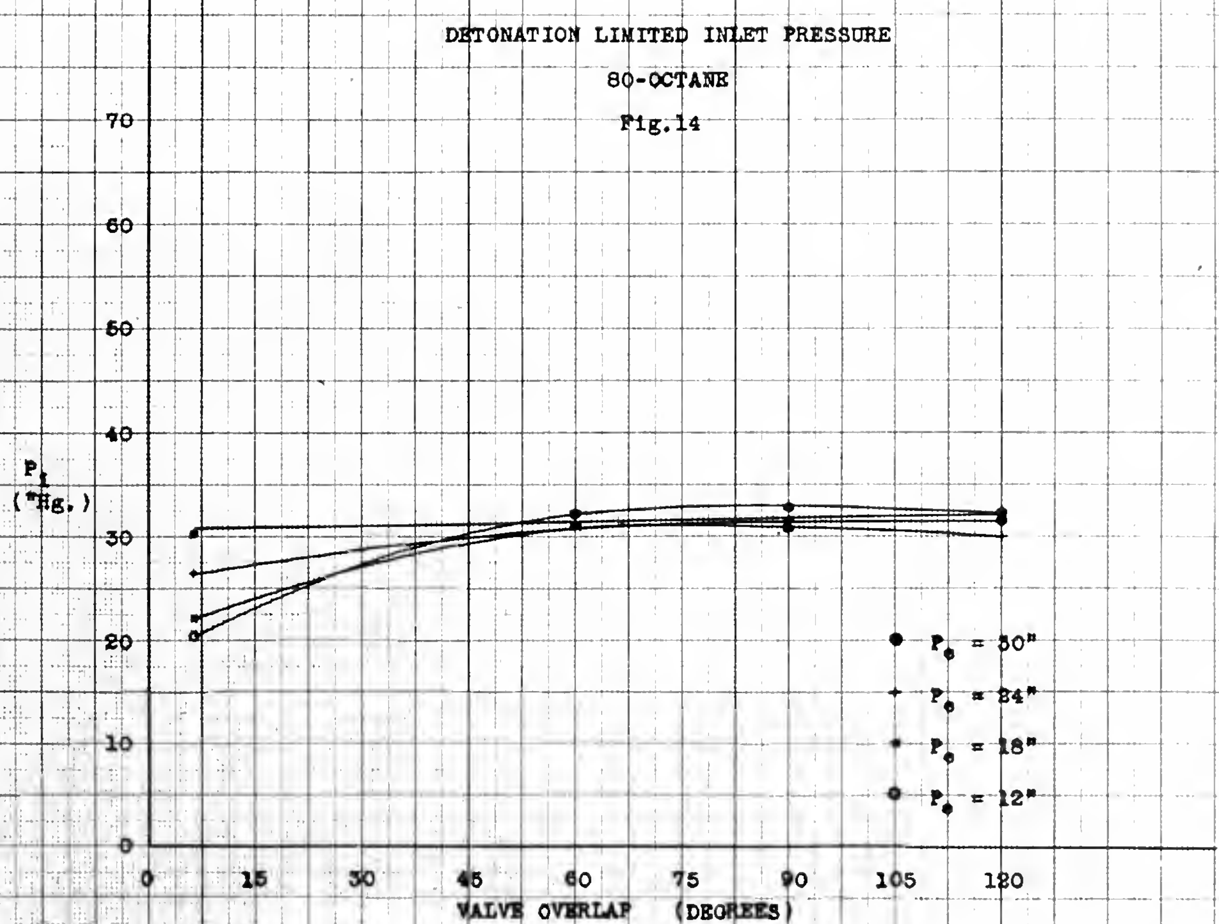



DETONATION LIMITED INLET PRESSURE
DI-ISO-BUTYLENE
Fig.11
70
60
50
40
30
20
10
0
P1
("Hg.)
1000 R.P.M.
1500 R.P.M.
2000 R.P.M.
2500 R.P.M.
0
15
30
45
60
75
90
105
120
VALVE OVERLAP (DEGREES)

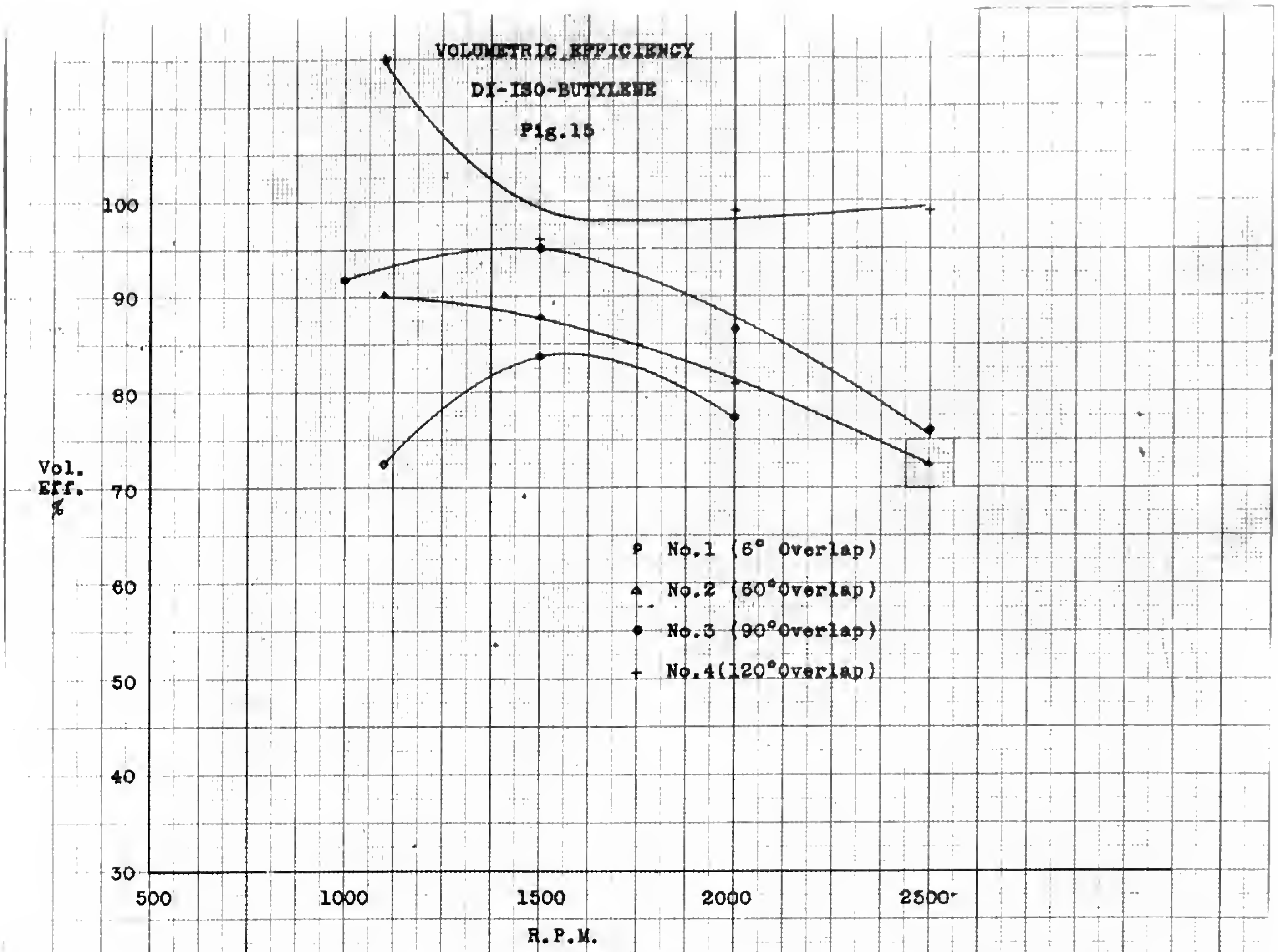

DETONATION LIMITED INLET PRESSURE
80-OCTANE
Fig.12
70
60
50
40
30
20
10
0
P1
("Hg.)
1000 R.P.M.
1500 R.P.M.
2000 R.P.M.
2500 R.P.M.
3000 R.P.M.
0
15
30
45
60
75
90
105
120
VALVE OVERLAP (DEGREES)



DETONATION LIMITED INLET PRESSURE
DI-ISO-BUTYLENE
Fig.13
70
60
50
40
P_1
("Hg.)
30
20
10
0
0
15
30
45
60
75
90
105
120
VALVE OVERLAP (DEGREES)
P_e = 30"
P_e = 24"
P_e = 18"
P_e = 12"



DETONATION LIMITED INLET PRESSURE
80-OCTANE
Fig.14
70
60
50
40
P_1
("Hg.)
30
20
10
0
0
15
30
45
60
75
90
105
120
VALVE OVERLAP (DEGREES)
P_e = 30"
P_e = 24"
P_e = 18"
P_e = 12"


VOLUMETRIC EFFICIENCY
DI-ISO-BUTYLENE
Fig.15
Vol. Eff. %
100
90
80
70
60
50
40
30
No.1 (6° Overlap)
No.2 (60°Overlap)
No.3 (90°Overlap)
No.4(120°Overlap)
500
1000
1500
2000
2500
R.P.M.

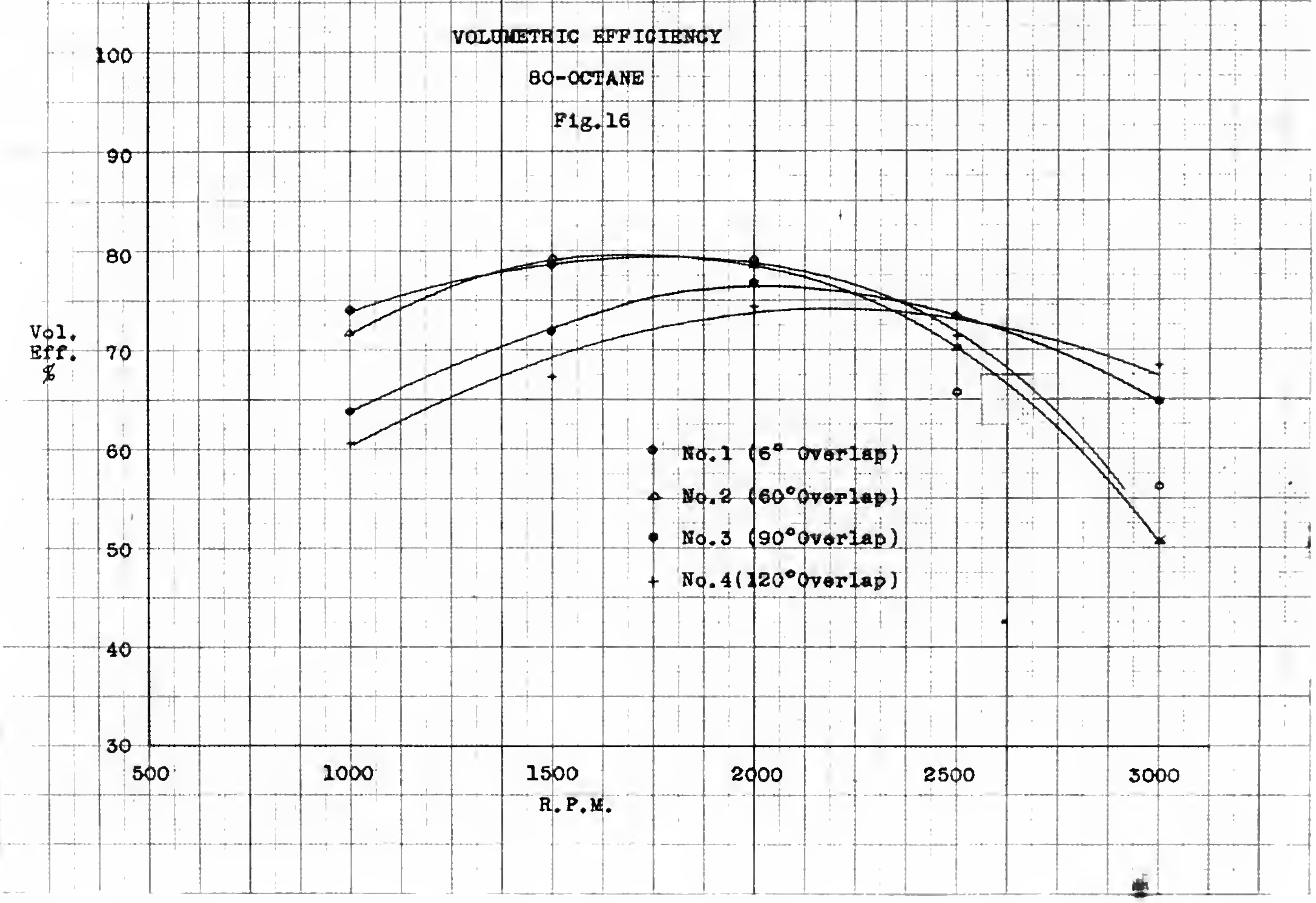

VOLUMETRIC EFFICIENCY
80-OCTANE
Fig.16
Vol. Eff. %
100
90
80
70
60
50
40
30
No.1 (6° Overlap)
No.2 (60°Overlap)
No.3 (90°Overlap)
No.4(120°Overlap)
500
1000
1500
2000
2500
3000
R.P.M.

TABLE I

Shaft Number	1	Oil Temperature	140° F
Overlap	6°	Jacket Temperature	212° F
Compression Ratio	7	Inlet Temperature	140° F
Spark Advance	18° BTC	Fuel-Air Ratio	.08

RUN	RPM	B.L.	F.L.	P_i	P_e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T_b	ΔP	P_b	B.L. + F.L.	IHP	IMEP	ISFC
								80 Octane									
1	1000	14.25	-5.15	22.98	30.00	.515	.00675	.000540	1	8.0	77	1.5	52.33	19.4	3.88	82.3	.502
2	1500	15.4	-6.45	24.73	30.00	.515	.01138	.000910	1	10.6	77	4.1	50.98	21.85	6.56	92.7	.500
3	2000	16.6	-7.25	29.98	30.00	.515	.01890	.001515	1	14.3	77	12.0	48.13	23.85	9.54	101.2	.572
4	2500	19.05	-8.05	37.23	30.00	.725	.02435	.001948	2	9.1	77	4.95	48.23	27.1	13.55	115.0	.517
5	3000	19.3	-9.1	47.23	30.00	.725	.03170	.002540	2	10.78	77	7.45	54.43	28.4	17.04	120.5	.537
6	2000	19.95	-6.9	30.43	30.00	.515	.01767	.001412	1	13.7	72	10.35	48.28	26.85	10.74	114.0	.473
7	2000	16.85	-6.0	26.43	24.00	.515	.01515	.001212	1	12.55	72	7.2	49.23	22.85	9.14	97.0	.478
8	2000	13.2	-5.75	22.03	18.00	.515	.01338	.001070	1	11.6	72	5.75	49.68	18.95	7.58	80.4	.508
9	2000	12.9	-5.3	20.68	12.00	.515	.01198	.000958	1	10.9	72	4.6	49.93	18.2	7.28	77.2	.474
							Di-iso-butylene										
10	1100	7.7	-3.8	50.98	30.00	.515	.01900	.001520	1	14.8		9.15	63.08	41.4	9.1	175.8	.602
11	1500	11.8	-4.9	54.28	30.00	.515	.02710	.002170	1	18.6		19.5	59.93	46.6	13.98	198.0	.560
12	2000	10.6	-6.1	58.18	30.00	.725	.03580	.002860	2	12.0		8.0	64.48	46.6	18.62	198.0	.552
13	2500	-	-	70.00	30.00	.725	Incipient	Detonation			Not		Reached				
14	2000	36.2	-6.6	43.95	30.00	.515	.02800	.002240	1	19.0	77	23.4	54.01	42.8	17.13	182.0	.471
15	2000	35.2	-6.0	43.9	24.00	.515	.02665	.002130	1	18.4	77	19.7	57.70	41.2	16.50	175.0	.465
16	2000	35.5	-5.5	43.6	18.00	.515	.02610	.002085	1	18.1	77	19.0	57.50	41.0	16.40	174.0	.458
17	2000	33.7	-4.9	41.0	12.00	.515	.02480	.001980	1	17.55	77	17.0	58.30	38.6	15.44	163.8	.462
18	2000	33.3	-5.0	40.8	8.60	.515	.02450	.001960	1	17.5	77	17.2	57.80	38.3	15.31	162.4	.462

TABLE II

Shaft Number	2	Oil Temperature	140° F
Overlap	60°	Jacket Temperature	212° F
Compression Ratio	7	Inlet Temperature	140° F
Spark Advance	18° BTC	Fuel-Air Ratio	.08

RUN	RPM	B.L.	F.L.	P_i	P_e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T_b	ΔP	P_b	B.L. + F.L.	IHP	IMEP	ISFC
								80 Octane									
19	1000	17.8	-3.5	25.55	30.00	.515	.00726	.000580	1	8.4	80	2.15	39.90	21.30	4.26	90.4	.491
20	1500	20.8	-4.5	26.70	30.00	.515	.01260	.001070	1	11.3	80	6.70	38.35	25.3	7.58	107.4	.508
21	2000	25.4	-5.4	32.30	30.00	.515	.02020	.001615	1	14.9	80	13.00	50.80	30.8	12.31	130.8	.472
22	2500	26.7	-6.1	37.9	30.00	.725	.02640	.002110	2	9.5	80	5.95	47.45	32.8	16.40	139.0	.463
23	3000	31.9	-7.4	50.8	30.00	.725	.03840	.003070	2	12.3	80	10.50	56.75	39.3	23.60	166.8	.468
24	2000	25.4	-5.5	32.2	30.00	.515	.02020	.001616	1	14.9	80	13.10	50.80	30.9	12.36	131.0	.471
25	2000	25.6	-4.3	31.0	24.00	.515	.02000	.001600	1	14.8	80	10.00	64.95	29.9	11.98	126.9	.481
26	2000	26.7	-3.5	31.0	18.00	.515	.02030	.001620	1	15.0	80	10.25	65.10	30.2	12.08	128.0	.483
27	2000	28.8	-2.6	32.5	12.00	.515	.02090	.001670	1	15.2	80	11.70	64.00	31.4	12.55	133.1	.479
28	2000	29.9	-2.5	33.1	9.50	.515	.02210	.001770	1	15.7	80	12.35	63.95	32.4	12.96	137.5	.492
							Du-iso-butylene										
29	1100	39.6	-2.4	47.33	30.00	.515	.01870	.001500	1	14.7	76	7.75	72.78	42.0	8.40	178.2	.642
30	1500	42.1	-3.0	50.23	30.00	.515	.02630	.002100	1	18.1	76	17.60	63.10	45.1	13.58	191.3	.557
31	2000	42.3	-4.7	54.23	30.00	.725	.03500	.002800	2	11.8	76	7.40	66.43	47.0	18.80	199.4	.536
32	2500	40.4	-5.5	60.63	30.00	.725	.04370	.003500	2	13.8	76	11.55	66.68	45.9	22.95	194.8	.550
33	3000	-	-	70.00	30.00	.725	Incipient		Detonation		Not		Reached				
34	2000	42.0	-4.2	54.23	30.00	.725	.03500	.002800	2	11.8	76	7.40	66.43	46.2	18.50	196.0	.545
35	2000	41.3	-3.2	52.73	24.00	.515	.03400	.002720	2	11.6	76	28.80	64.63	44.5	17.80	189.0	.550
36	2000	41.0	-3.1	51.63	18.00	.515	.03480	.002780	2	11.7	76	31.80	59.73	44.1	17.65	187.0	.566
37	2000	41.5	-3.3	50.93	12.00	.515	.03370	.002700	2	11.6	76	30.70	59.80	43.8	17.52	185.9	.554
38	2000	39.5	-3.5	49.83	10.60	.515	.03340	.002670	2	11.5	76	29.70	60.43	43.0	17.20	182.4	.559

TABLE III

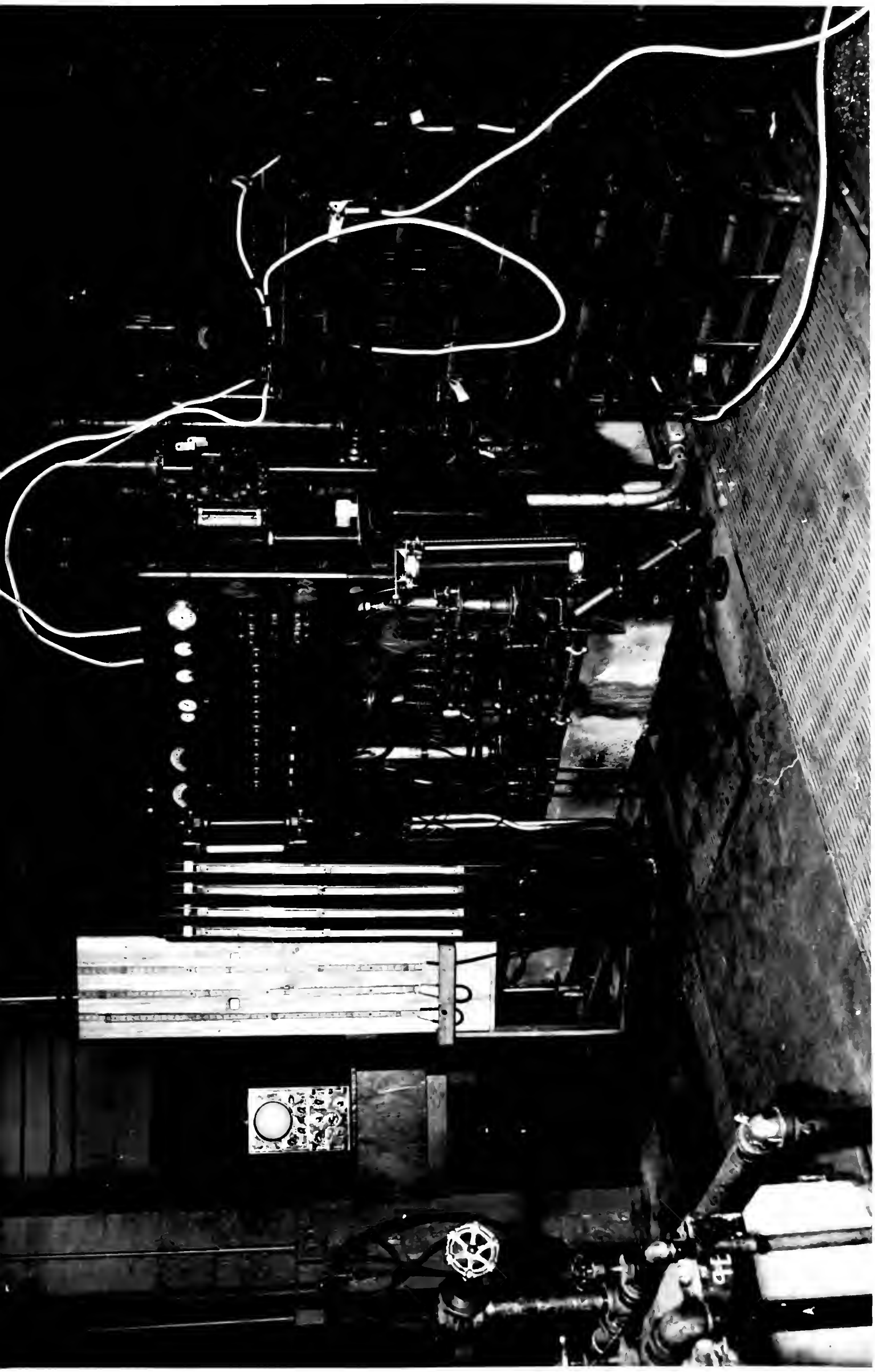
Shaft Number	3	Oil Temperature	140° F
Overlap	90°	Jacket Temperature	212° F
Compression Ratio	7	Inlet Temperature	140° F
Spark Advance	18° BTC	Fuel-Air Ratio	.08

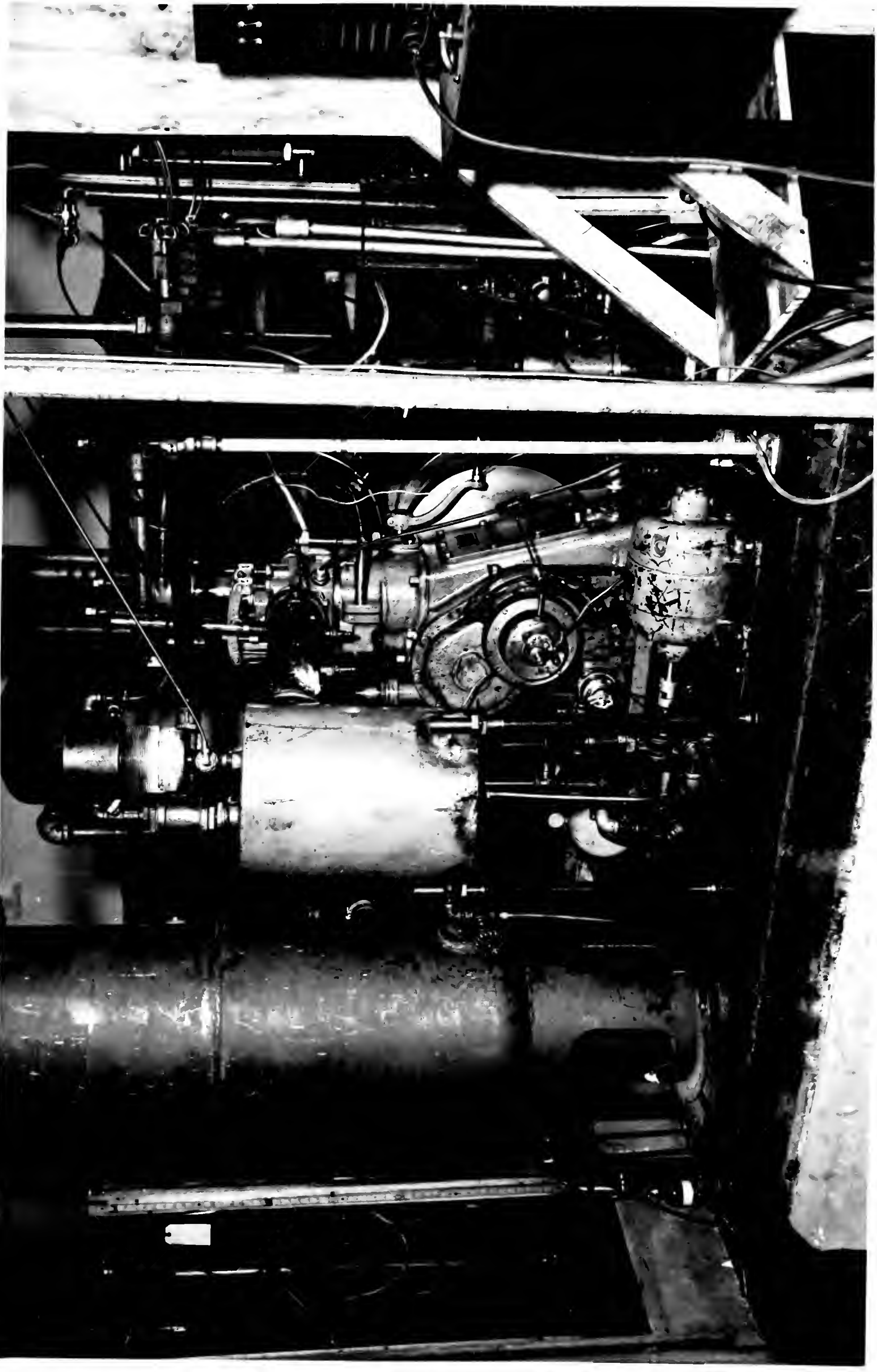
RUN	RPM	B.L.	F.L.	P_i	P_e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T_b	ΔP	P_b	B.L. +F.L.	IHP	IMEP	ISFC
								80 Octane									
39	1000	14.3	-4.2	25.77	30.00	.515	.00653	.000522	1	8.0	75	1.0	68.02	18.5	3.75	78.5	.501
40	1500	19.8	-4.9	28.52	30.00	.515	.01228	.000980	1	11.2	75	3.65	66.37	24.7	7.41	105.0	.476
41	2000	21.6	-6.5	30.77	30.00	.725	.01880	.001510	2	7.8	75	2.2	64.52	28.1	11.25	119.4	.482
42	2500	27.3	-7.3	38.42	30.00	.725	.02810	.002250	2	9.9	75	5.2	60.97	34.6	17.3	147.0	.468
43	3000	31.3	-8.6	51.2	30.00	.725	.03960	.003170	2	12.6	75	11.2	55.62	40.4	24.3	171.8	.469
44	2000	21.5	-6.5	30.77	30.00	.725	.01880	.001510	2	7.8	75	2.2	64.52	28.0	11.2	119.0	.486
45	2000	24.5	-5.8	30.92	24.00	.515	.02080	.001660	1	15.1	75	11.0	62.90	30.3	12.12	128.8	.492
46	2000	25.7	-5.0	31.42	18.00	.515	.02190	.001750	1	15.7	75	12.8	60.17	30.7	12.3	130.4	.512
47	2000	27.6	-4.4	32.42	12.00	.725	.02290	.001830	1	16.0	75	3.25	64.47	32.0	12.8	135.9	.514
48	2000	28.2	-4.1	33.02	9.20	.725	.02340	.001870	1	16.4	75	3.40	63.42	32.3	12.93	137.2	.521
							Di-iso-butylene										
49	1000	42.4	-3.7	50.3	30.00	.515	.02020	.001620	1	15.5	75	10.1	64.80	46.1	9.22	196.0	.632
50	1500	44.1	-4.8	51.5	30.00	.725	.02920	.002340	2	10.6	75	5.6	61.10	48.9	14.7	207.0	.573
51	2000	39.6	-6.0	52.82	30.00	.725	.03650	.002920	2	12.3	75	8.2	65.05	45.6	18.25	193.5	.577
52	2500	36.4	-7.1	56.3	30.00	.725	.04260	.003400	2	13.5	75	11.8	61.2	43.5	21.8	184.6	.561
53	3000	-	-	70.00	30.00	.725	Incipient	Detonation			Not		Reached				
54	2000	39.6	-6.0	52.3	30.00	.515	.03650	.002920	2	12.3	75	8.2	65.05	45.6	18.25	193.5	.577
55	2000	41.2	-4.9	52.0	24.00	.515	.03660	.002930	2	12.2	75	8.35	64.2	46.1	18.42	196.0	.572
56	2000	44.0	-4.5	51.0	18.00	.515	.03910	.003130	2	12.7	75	9.65	63.2	48.5	19.4	206.0	.612
57	2000	45.6	-4.1	49.0	12.00	.515	.04020	.003220	2	12.9	75	10.4	62.3	49.7	19.9	211.0	.597
58	2000	46.1	-4.0	48.5	11.00	.515	.04080	.003270	2	13.1	75	10.8	61.95	50.1	20.05	212.5	.587

TABLE IV

Shaft Number	4	Oil Temperature	140° F
Overlap	120°	Jacket Temperature	212° F
Compression Ratio	7	Inlet Temperature	140° F
Spark Advance	18° BTC	Fuel-Air Ratio	.08

RUN	RPM	B.L.	F.L.	P_i	P_e	ORF.	AIR CONS.	FUEL CONS.	R	ROTO.	T_b	ΔP	P_b	B.L. + F.L.	IHP	IMEP	ISFC
								80 Octane									
60	1000	15.5	-4.1	28.55	30.00	.515	.00689	.000543	1	8.1	70	1.15	63.75	19.60	3.92	83.2	.407
61	1500	18.6	-5.4	29.35	30.00	.515	.01180	.000935	1	10.7	70	3.50	62.15	24.00	7.2	101.9	.468
62	2000	22.8	-6.4	31.55	30.00	.515	.01870	.001498	1	14.2	70	9.35	60.00	29.2	11.68	124.0	.462
63	2500	27.9	-7.6	38.55	30.00	.515	.02750	.002200	1	18.2	70	21.25	56.80	35.5	17.75	150.8	.446
64	3000	33.6	-8.4	50.85	30.00	.725	.04160	.003330	2	13.0	70	12.60	54.65	42.0	25.24	178.2	.475
65	2000	22.8	-6.2	31.50	30.00	.515	.01870	.001500	1	14.2	70	9.35	60.00	29.0	11.6	123.0	.466
66	2000	24.4	-5.6	30.00	24.00	.515	.02030	.001625	1	15.0	70	9.90	65.65	30.0	12.0	127.2	.488
67	2000	24.5	-5.1	31.25	18.00	.515	.02280	.001820	1	16.1	70	12.75	64.90	29.6	11.84	125.5	.553
68	2000	26.3	-4.4	33.05	12.00	.515	.02480	.001970	1	16.9	70	15.05	64.20	30.7	12.28	130.2	.579
69	2000	30.8	-3.8	34.35	8.60	.515	.02600	.002080	1	17.5	70	17.0	63.35	34.6	13.84	146.9	.541
								Di-iso-butylene									
70	1100	51.9	-4.0	50.86	30.00	.515	.02565	.002050	2	9.7	75	16.55	63.71	55.9	12.30	237.0	.600
71	1500	40.2	-5.4	51.00	30.00	.515	.02930	.002350	2	10.6	78	22.20	62.51	45.6	13.67	193.5	.619
72	1700	42.8	-5.1	51.21	30.00	.515	.03440	.002750	2	11.7	78	31.3	60.81	47.9	16.30	203.0	.607
73	2100	55.2	-6.0	56.0	30.00	.725	.04200	.003380	2	13.4	75	11.05	63.65	61.2	25.67	259.5	.473
74	2500	-	-	70.00	30.00	.725	Incipient	Detonation			Not		Reached				
75	2000	37.8	-6.1	55.6	30.00	.725	.04180	.003350	2	13.3	78	11.03	63.60	43.9	17.56	186.3	.687
76	2000	40.3	-5.1	53.1	24.00	.725	.04060	.003250	2	13.0	78	10.55	63.20	45.4	18.18	192.9	.644
77	2000	40.1	-4.5	51.5	18.00	.725	.03970	.003180	2	12.8	78	9.80	64.60	44.6	17.80	189.1	.643
78	2000	38.9	-4.4	50.3	12.00	.725	.03810	.003050	2	12.5	78	9.00	65.00	43.3	17.33	183.8	.632





Thesis 8094
M184 McElroy
The effect of valve overlap on detonation limited engine performance.